THE JOURNAL OF Organic Chemistry®

VOLUME 42, NUMBER 4

FEBRUARY 18, 1977

The Influence of the Neighboring Phenylthio Group on the Solvolytic Reactivity of Allylic Compounds. An Example of an Internal S_N2' Reaction

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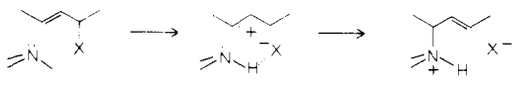
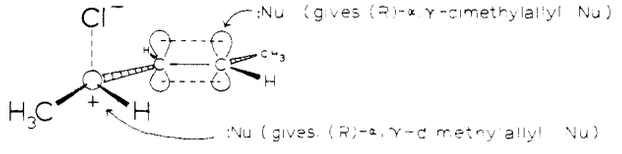
Received March 26, 1976

The rate and solvolysis products of *trans*-4-(phenylthio)-2-cyclohexenyl *p*-nitrobenzoate (**1b**), its cis isomer (**2b**), *trans*-6-(phenylthio)-2-cyclohexenyl *p*-nitrobenzoate (**3b**), and related compounds were investigated. The product compositions from **1b, 2b,** and **3b** were quite similar and a common intermediate for all three was suggested. The solvolysis rate for **3b** was strongly accelerated, through sulfur participation, while the rates for **1b** and **2b** showed marginal acceleration. From these results it is inferred that S_N2' reactions, under conditions where the leaving group is the leading element of the reaction, are neither extremely facile nor stereospecific.

Since the pioneering paper of Stork and White,[2] there has been general acceptance[3] of the idea that the S_N2' reaction requires a syn (cis) relationship between entering and leaving groups. They found that *trans*-6-alkyl-2-cyclohexenyl 2,6-dichlorobenzoates underwent S_N2' reactions with piperidine and sodium malonate ester in a syn manner producing therefore *trans*-3-alkyl 4-substituted cyclohexenes. The reaction was second order and appeared not to involve rearrangement of starting material or products. Subsequently, theoretical agreements have been advanced to explain their observations.[4,5] More recently Bordwell et al.[6] have synthesized a number of γ-arylsulfonyl allylic halides which would seem to be well suited to S_N2' displacement by nucleophiles. They find, however, that these compounds are generally quite unreactive, a fact which has led them to question the attainability of the concerted S_N2' mechanism. They suggest that many of the reported examples may in fact proceed by mechanisms which involve carbonium ion type reactions and they classify the classic examples of Stork and White as S_Ni reactions (a variant of an ion pair mechanism) and picture them in the following manner.[6a] The importance of ion pairs



in displacement reactions of allylic substrate has also been recently emphasized by Sneen et al.[7] They report[7a] that the kinetic, product, and stereochemical data for the competitive substitution by solvent (alcohol or alcohol–H_2O) and external nucleophiles (N_3^- or NCS^-) on α,γ-dimethylallyl chloride are best accommodated by an ion pair mechanism. The evidence would indicate that the first formed intimate ion pairs are asymmetric and thereby give rise to an optically active product of assumed inverted configuration. The intimate ion pairs can interconvert or further dissociate to a meso solvent separated ion pair which rapidly collapses to give racemic product. It was not known whether the attack by external nucleophile took place at C-α (with assumed inversion) or at C-γ with a syn stereochemistry which would give the same stereochemical result, inversion.

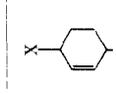
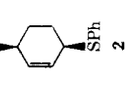
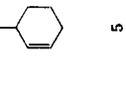
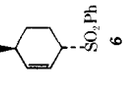
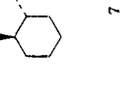
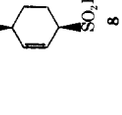


In a companion study Sneen and Carter[7b] reported what appears to be an authentic example of an S_N2' reaction of phenoxide with α-methylallyl chloride. In this case the data pointed to a rate-determining displacement by phenoxide on a discrete intimate ion pair to give 17% S_N2' and 83% S_N2 type products. Although the stereochemistry of the S_N2' component was not determined, a recent theoretical study[5] of the S_N2' reaction by Epiotis et al. concluded that both nonbonded and electrostatic interactions favor syn over anti attack when the nucleophile is neutral and the leaving group departs as an anion. They expected these conclusions to hold regardless of whether one had a classical S_N2' reaction or an ion pair variant.

This study was undertaken to shed light on the stereochemistry and facility of S_N2' reactions conducted under ionizing conditions. In this paper we report our efforts to find evidence for sulfur participation in the solvolysis of compounds such as *trans*-4-(phenylthio)-2-cyclohexenyl *p*-nitrobenzoate (**1b**) and its cis isomer (**2b**). They contain a good internal nucleophile which is forced to participate in a predetermined manner, anti S_N2' for **1b** and syn S_N2' for **2b.** The phenylthio substituent (PhS) has previously been shown to be a good neighboring group by Goering and Howe,[8] who reported that the trans/cis rate ratio for the solvolysis (80% aqueous ethanol) of 2-(phenylthio)cyclohexyl chloride is

Table I. Solvolysis Rate Constants and Activation Parameters for *p*-Nitrobenzoates in TFE

a, X = OH
b, X = OPNB (*p*-nitrobenzoate)
c, X = ODNB (3,5-dinitrobenzoate)
d, X = OCH_2CF_3

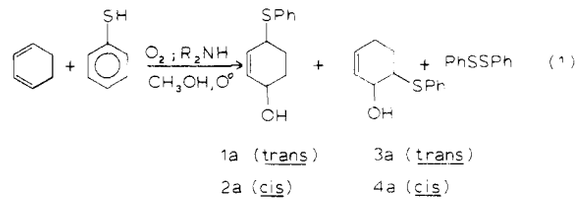
	 1 (52939-10-3)[e]	 2 (52939-09-3)	 3 (60789-30-2)	 5 (38313-01-8)	 6 (60789-31-3)	 7 (60789-32-4)	 8 (60789-33-5)
k_{rel} (X = OPNB; 120 °C)	1.38	0.27	29.5	1.0	0.005	0.014	0.0016
$k \times 10^5$, s^{-1} (°C)[b]	2.00 (79.59)	1.52 (100.08)	9.08 (49.76)	1.57 (79.59)	0.0186 (120.0)[d]	0.562 (120.0)[d]	0.0063 (120)[b]
	4.95 (89.79)	3.62 (110.0)	20.2 (59.86)	4.03 (89.79)			
	11.36 (99.97)	10.19 (120.0)	31.0 (65.14)	8.55 (99.87)			
$\Delta H^{\ddagger}$, kcal/mol	21.7 ± 0.1	27.1 ± 2.6	16.6 ± 0.5	21.1 ± 0.1			
$\Delta S^{\ddagger}$, eu	−18.9 ± 0.3	−8.5 ± 6.8	−25.8 ± 1.6	−20.9 ± 2.9			

[a] Computed from the rate of the corresponding 3,5-dinitrobenzoate **6c** assuming $5.1k_{4b} = k_{4c}$ since $k_{5c}/k_{5b} = 5.1$ in TFE. The rate constant measured on **6b** at 20% reaction was ca. 2×10^{-7} s^{-1}. [b] The standard deviation for the rate constants are between 1 and 5% for all entries except for the last two under 5b, where they were ca. 8%, and 8b, whose rate could be measured only out to 10% reaction. [c] Registry no.

nearly 10^6. Our aim then was to see whether **1b** or **2b** would undergo solvolysis with sulfur participation, which could be detected either kinetically or by product analysis.

Results

The cooxidation[9] of thiophenol and 1,3-cyclohexadiene was expected to provide a high-yield synthetic route to 4-(phenylthio)- and 6-(phenylthio)-2-cyclohexen-1-ols (eq 1). Three

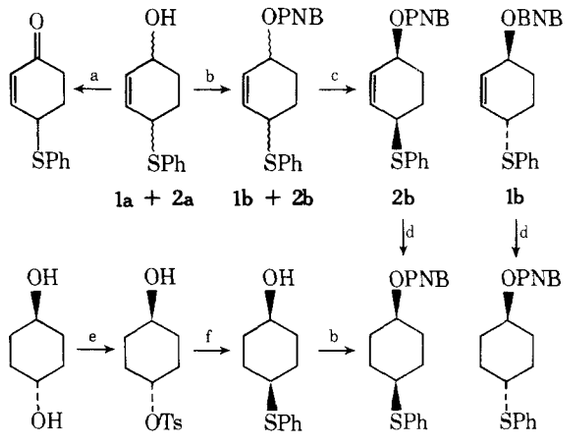


(1)

1a (trans) 3a (trans)
2a (cis) 4a (cis)

allylic alcohols were isolated in nearly equal amounts from this reaction mixture by column chromatography. One of these was shown to be **3a** by reduction to, and comparison with, an authentic sample of *trans*-2-(phenylthio)cyclohexanol (**7a**). The identities of the other two, **1a** and **2a**, were established by the route outlined in Scheme I. A careful search for **4a** was made

Scheme I. Stereochemical Assignment of *cis*- and *trans*-4-(Phenylthio)-2-cyclohexen-1-ol



a, 2,3-dichloro-5,6-dicyano-1,4-benzoquinone; b, *p*-nitrobenzoyl chloride, pyridine; c, chromatography and fractional recrystallization; d, H_2, $(C_6H_5P)_3 \cdot Rh(I)Cl$, C_6H_6, C_2H_5OH; e, $CH_3C_6H_4SO_2Cl$, pyridine; f, C_6H_5SNa, H_2O–C_2H_5OH.

but none was detected (see Experimental Section for details).

trans-2-(Phenylthio)cyclohexanol (**7a**) was prepared from cyclohexene oxide and sodium thiophenoxide. The *p*-nitrobenzoates and 3,5-dinitrobenzoates used in this study were generally prepared from the corresponding alcohols by standard procedures. *trans*-4-Phenylsulfonyl-2-cyclohexenyl *p*-nitrobenzoate (**6b**) and 3,5-dinitrobenzoate (**6c**) were prepared by hydrogen peroxide oxidation of **1b** and **1c**, respectively. In a similar manner the cis isomer, **8b**, was prepared from sulfide **2b**.

The solvolysis rates were measured using the ampule technique in 2,2,2-trifluoroethanol (TFE).[10] Except as noted, good first-order plots were obtained for all compounds up to 75% reaction. The initial concentration of *p*-nitrobenzoate was kept below ca. 1.5×10^{-2} M, for at higher concentrations some autocatalysis was observed, as evidenced by an upward drifting of the first-order rate constant. Few 3,5-dinitrobenzoates were measured in TFE because of their low solubility. The solvolysis of sulfones **6b** and **8b** was quite slow in TFE and could be followed to only 20 and 10% reaction, respectively, after which severe discoloring of the medium and the production of an acidic by-product(s) occurred. A control ex-

periment showed that these acidic products were not the result of TFE decomposition at the elevated temperatures used for the solvolysis. As a cross-check the rate of the more reactive 3,5-dinitrobenzoate **6c** was also measured and corrected for the differences in leaving group ability as judged by $k_{5c}/k_{5b} = 5.1$ in TFE. The rate of **6b** obtained in this way was in good agreement with the value obtained directly. With the exception of **6b, 6c,** and **8b** experimental infinity titers were used to calculate all specific rate constants. The relative rates for all PNB's calculated at 120 °C, specific first-order rate constants, and activation parameters for the TFE runs are recorded in Table I.

Solvolysis products for **1b, 2b,** and **3b** were determined in TFE containing 2 equiv of 2,6-lutidine. In all three cases the ^{1}H NMR spectrum of the crude reaction mixture revealed the absence of elimination products. All three *p*-nitrobenzoates gave a similar product distribution consisting of **1d, 2d,** and **3d** in ca. 1:1:5 ratio. In addition, **3b** gave 7% of an internal return product, **1b.** In none of the preparative runs was anything isolated which could be assigned to either **4b** or **4d.** The products were identified by ^{1}H NMR spin–spin decoupling studies and comparison of these spectra to those of the corresponding alcohols and benzoate esters (see Experimental Section for details). The product mixtures are recorded in Table II.

Discussion

As mentioned earlier, *trans*-2-(phenylthio)cyclohexyl chloride shows greatly enhanced reactivity [k(trans)/k(cis $\approx 10^6$] due to sulfur participation. Of the seven *p*-nitrobenzoates studied in this paper, the analogous cyclohexenyl sulfide, **3b,** is the most reactive. This reactivity is most reasonably ascribed also to sulfur participation leading to ion **9.** The mag-

9

nitude of the acceleration is certainly greater than 29.5 (k_{3b}/k_{5b}) because the rate of **5b** is certainly faster than that expected for unassisted **3b.** The rate constant k_{5b} can, however, be corrected for the retardation to be expected from a nonparticipating phenylthio group through a Hammett plot and thereby yield an estimate of k_{3b} (unassisted). Thus using the solvolysis rates of **5b** and **6b,** the known σ_I values[11] of $PhSO_2$ and PhS, and the assumption that the substituent effects at the α carbon of a developing allylic cation are similar to those at the γ carbon, one estimates that k_{3b} (observed)/k_{3b} (unassisted) is greater than 600. This strongly suggests sulfur participation during the initial ionization. The fact that the acceleration is considerably less in the cyclohexenyl system than in the cyclohexyl system is probably a reflection of the reduced electron demands in the allylic compound.[12]

The products isolated from the reaction are in accord with the postulated intermediate, **9,** since trans 1,2 ether, **3d,** but no cis 1,2 ether, **4d,** was isolated. Furthermore, if the intermediate were an open allylic cation, one might expect the amount of 1,4 products to exceed 1,2 products.[3] This is not the case; the major isolated product (ca. 73%) was trans 1,2 ether, **3d.** Thus sulfur bridging has apparently enhanced the formation of 1,2 products. Similar arguements have been used to explain the tendency toward the formation of 1,2-addition products in the reaction of halogens and sulfenyl chlorides with conjugated dienes under kinetically controlled conditions.[3,13]

Because of the magnitude of the rate acceleration for **3b** and the predominance of trans 1,2-substitution product, with the absence of cis 1,2-substitution product, we feel that the cis and trans 1,4 ethers **1d** and **2d** arise mainly from syn and anti S_N2' attack of solvent on bridged ion **9** rather than from a second open allylic cation. Their formation via the route **3b** → (**1b** + **2b**) → **1d** + **2d** is untenable, since **1b** and **2b** are stable under the reaction conditions. Thus the product data suggest that both syn and anti S_N2'-like processes are probably energetically comparable. A similar conclusion was recently expressed by Heasley et al.[13] based on stereochemical observations for the addition of bromine to dienes. In our case the mixture of 1,4 ethers probably results from a balancing of electrostatic repulsion between the positively charged sulfur and the developing positive charge on TFE's oxygen which favors anti solvent attack and nonbonded interactions which favor syn attack.[5]

Table II. Products Isolated from Preparative Solvolysis in TFE[a]

Starting material	Product ratios[b]			
	1d	2d	3d	% yield
1b	16	16	68	84
2b	16	12	72	68
3b	11	12	77	78[c]

[a] Buffered with 2 equiv of 2,6-lutidine. [b] The ratios were determined by careful integration of the appropriate ^{1}H NMR signals. The 1,4 isomers, **1d** and **2d,** were arbitrarily assigned. [c] *p*-Nitrobenzoate, **1b,** was also isolated (7%).

The product distribution from all three sulfides, **1b, 2b,** and **3b,** are very similar. The fact that each gives approximately a 14:13:73 ratio of **1d**:**2d**:**3d** suggests that sulfur is participating in the 1,4 sulfides, **1b** and **2b,** just as it was in **3b.** Such participation does not, however, result in large rate accelerations for **1b** and **2b;** their rates are comparable to that of **5b.** The fact that PNB's **1b** and **2b** are about as reactive as the unsubstituted PNB, **5b,** does, however, suggest some sulfur assistance, since in the absence of participation, the electron-withdrawing effect of PhS should cause **1b** and **2b** to solvolyze more slowly than **5b.** Estimates of the unassisted rates for **1b** and **2b** were obtained via a Hammett plot using the rate data for model compounds **5b, 6b,** and **8b,** together with the known σ_I values for phenylthio (0.21) and phenylsulfonyl (0.52) groups.[11] The results suggest that the observed rate of **1b** is about 30 times faster than expected in the absence of participation and that the rate of **2b** is about 10 times faster. These rate accelerations are modest, and indicate that these internal S_N2' reactions show little stereospecificity and are not very facile. In fact, if one makes the reasonable assumption that **1b** and **2b** solvolyze by two pathways, a k_Δ pathway involving sulfur assistance and a k_s pathway involving solvent assistance,[14-16] one calculates that the amount of reaction which proceeds through the k_Δ pathway at 120 °C for **1b** is 96%[17] and for **2b** is 91%. The intervention of a small amount of a solvent assisted, k_s pathway could help explain the tendency of **1b** and **2b** to give less trans 1,2 ether, **3d,** and more 1,4 ethers, **1d** and **2d,** since k_s pathways would be expected to yield primarily unrearranged product of inverted configuration.

In recent years Bordwell[6] has searched, with little success, for examples of S_N2' reactions. His studies were conducted under conditions where substrate ionization was discouraged and nucleophilic attack encouraged. As a result of these studies, serious doubts concerning the attainability of concerted S_N2' reactions were raised. In this work we searched for intramolecular S_N2' reactions under conditions where the leaving group was the leading element of the reaction. Under these conditions one might expect that the incipient positive charge would encourage such a reaction. However, even under these apparently favorable conditions, we find, with our

substrate, that syn and anti S_N2' processes are energetically similar and that in either case they are not very facile.

Experimental Section

The ^1H NMR spectra were obtained on a Varian A-60 or JEOL MH-100 NMR spectrometer with Me_4Si as an internal standard. Infrared spectra were recorded with a Perkin-Elmer 337 spectrometer as neat liquids or as solutions as indicated. Gas–liquid partition chromatography was done on an Aerograph A90-P3 (thermal conductivity detector) gas chromatograph. All melting points are uncorrected.

Cooxidation of 1,3-Cyclohexadiene and Thiophenol. A modification of the procedure of Oswald[9] was used to prepare a mixture of 4- and 6-(phenylthio)-2-cyclohexenols. In a typical experiment 20.8 g (0.25 mol) of 1,3-cyclohexadiene and 2.9 g (0.04 mol) of freshly distilled diethylamine dissolved in 250 ml of methanol were cooled to 0 °C by means of an ice–water bath. Oxygen was bubbled through the solution and the flow adjusted so that the gas left the reaction mixture at a rate of 1 bubble every 10–15 s. Freshly distilled thiophenol (47.6 g, 0.43 mol) was added dropwise over a period of 8 h. The temperature was maintained at 0–5 °C for a total of 16 h and then allowed to warm to room temperature. The oxygen bubbling was continued for a total of 24 h.

The reaction mixture was cooled to −78 °C and the crystalline precipitate was filtered by suction, washed with a small amount of cold methanol, and dried to yield 29.5 g (97%) of diphenyl disulfide, mp 59–61 °C. The methanol solution was concentrated in vacuo and the residual product pumped out for 2 h at room temperature (0.2 mm) to remove any traces of solvent. The yield of unpurified alcohols was 29.2 g (99.0%).

The unpurified alcohols were chromatographed on a column of Florisil (Floridin C, 100/200 mesh) slurry packed in hexane. In a typical experiment, 4.1 g of unpurified alcohol was placed on the column (2.5 × 100 cm) and eluted with 1.5 l. of 50% benzene in hexane, 2.5 l. of 90% benzene in hexane, 1.5 l. of benzene, 1.5 l. of 8% ether in benzene, 1 l. of 50% ether in benzene, and 2.3 l. of 80% ether in benzene. Similar results could be obtained eluting first with hexane followed by 5% ether in hexane and gradually increasing the ether content.

Fractions of 20–25 ml were collected and analyzed by TLC on 10 × 20 cm silica gel HF plates using benzene and ether as the eluents.

Fraction 1: 0.18 g (3.7%); one spot on TLC, R_f 1 in benzene, identical with that of known diphenyl disulfide.

Fraction 2: 1.22 g (25.1%); one major spot with R_f 0.08–0.1 (benzene) and R_f 0.65 (ether). This fraction contains some material which has R_f values identical with those in fraction 3. ^1H NMR (100 MHz, $CDCl_3$) δ 1.40–2.44 (m, 4 H, $-CH_2-$), 3.08–3.88 (m, 2 H, CHS, OH–D_2O exchangeable), 4.13 (broad d, 1 H, J = 6 Hz, CHO), 5.42–6.04 (m, 2 H, vinyl), 6.84–7.88 (m, 5 H, ArH). This fraction was subsequently shown to be nearly pure **3a**.

Fraction 3: 2.32 g (47.8%); one spot when the TLC plate was developed in benzene (R_f 0.04). With ether development of the TLC plate two spots appeared (R_f 0.52 and 0.45). ^1H NMR (100 MHz, $CDCl_3$) δ 1.12–2.26 (m, 4 H, CH_2), 3.8 (s, 1 H, OH–D_2O exchangeable), 3.78 (broad s, 1 H, CHS), 4.18 (broad s, 1 H, CHO), 5.8–6.2 (m, 2 H, vinyl), 7.2–7.96 (m, SH, ArH). Fraction 3 was subsequently shown to be an approximately equal mixture of **1a** and **2a**.

Fraction 4: 0.32 g (6.5%); two spots with R_f (ether) 0.67 and 0.76. The spot at 0.76 did not absorb I_2 but did show under the UV lamp.

Fraction 5: 0.52 g (10.7%); one spot, R_f (ether) 0.79, which did not absorb I_2.

Fraction 6: 0.30 g (6.2%); contains series of components with R_f values (ether) ranging from 0 to 0.03 plus traces of fractions 2–5. It was a highly colored material.

The ^1H NMR spectra ($CDCl_3$) of fractions 4 and 5 showed none of the absorpiton shown in the spectra of fractions 2 and 3. No spectrum was run on fraction 6. Other column chromatography gave similar results.

Diimide Reduction of the Cooxidation Products. The procedure of Baird[18] was used to reduce the products of the cooxidation of 1,3-cyclohexadiene and thiophenol. To a stirred solution of the cooxidation reaction mixture (11.76 g, 0.057 mol, used without purification) and 58.2 g (0.3 mol) of potassium azodicarboxylate in 250 ml of methanol was added dropwise 36 g (0.6 mol) of acetic acid in 50 ml of methanol. As the addition proceeded, the temperature rose until the methanol gently refluxed. The reaction mixture was stirred for an additional 1 h after the acetic acid addition was complete. The ^1H NMR spectrum of an aliquot revealed the presence of vinylic absorption. An additional 42 g (0.216 mol) of potassium azodicarboxylate was added to the reaction mixture and 26.4 g (0.44 mol) of acetic acid added to the cooled reaction mixture. Stirring was continued for 5 h after the addition, during which time the mixture was allowed to warm to room temperature. A water-soluble white solid had formed during the reaction. Water was added to the reaction mixture to dissolve the solid and was extracted several times with ethyl ether. The combined ethereal extracts were washed ($NaHCO_3$, saturated NaCl solution), dried ($MgSO_4$), and concentrated in vacuo. The resulting solid was filtered and washed with ether. The ethereal filtrate was washed as before, dried, and concentrated. A ^1H NMR of the residue indicated the presence of vinyl protons. The integrated ratio of aromatic protons to vinyl protons was 3.2:1. This corresponds to a 25% reduction using azodicarboxylate.

Complete reduction of the mixture was accomplished with *p*-toluenesulfonylhydrazine[19] using a modification of the procedure described by Garbisch.[20] A solution of the residue for the azodicarboxylate reduction and 55.8 g (0.3 mol) of *p*-toluenesulfonylhydrazine (Aldrich Chemical Co.) in 300 ml of *p*-dioxane and 50 ml of triethylamine was refluxed under nitrogen for 24 h. The dioxane was removed in vacuo, and the residue taken up in ether. The ethereal solution was washed with 3 N potassium hydroxide, 3 N HCl, and 5% $NaHCO_3$, and dried over anhydrous $MgSO_4$. Removal of the ether in vacuo yielded 17.02 g (143%) of a dark brown liquid. ^1H NMR analysis indicated that the excess weight present in the reduced material came from unreacted *p*-toluenesulfonylhydrazine (or an impurity in that material) and dioxane.

GLC analysis of the reduction mixture on a 5-ft column of 5% Carbowax 20M on 60/80 mesh Chromosorb W at 190 °C showed two major peaks with retention times of 22.5 min for the 1,2 isomer and 53.7 min for the 1,4 isomers. The relative amount of the 1,2 and 1,4 isomers was obtained by cutting out and weighing the individual peaks. The average result of two determinations was that 34.5 ± 1.9% of the reduced alcohols were 1,2 isomer(s) and 65.5 ± 1.0% were 1,4 isomers. This is consistent with the results obtained in the column chromatography of the cooxidation reaction mixture (see above).

A similar tosylhydrazine reduction of fraction 2 from the cooxidation chromatogram gave **7a** with only traces of the 1,4 alcohols as established by GLC, ^1H NMR, and IR comparison with authentic **7a**.

***cis*-4-(Phenylthio)cyclohexanol).** The general method of Eliel[21] was used to prepare a 26% yield of *cis*-4-(phenylthio)cyclohexanol (mp 74–76 °C, lit.[22] 73–75 °C) from *trans*-4-hydroxycyclohexyl tosylate[23] and sodium thiophenolate. Spectral properties follow: IR ($CHCl_3$) 3600 (sharp), 3450 (broad), 2925, 1580, 1420, 1350, 1290, 1200 (broad), 1090, 1045, 1025, 995, 955, 885, 860 cm^{-1}.

***trans*-2-(Phenylthio)cyclohexanol (7a).** A solution of 27.5 g (0.25 mol) of thiophenol and 24.5 g (0.25 mol) of cyclohexene oxide in 75 ml of dry ethanol containing 0.5 g (0.22 g-atom) of sodium was allowed to stand with occasional swirling for 4 days. The reaction mixture was neutralized with CO_2 and few drops of water, filtered, and concentrated in vacuo. Distillation of the residue yielded 34.8 g (61.5%) of the desired product, bp 105–106 °C (0.25 mm) [lit.[24] 130–132 °C (1 mm)]. Slight cooling of the distillate induced crystallization of a solid (mp 37–42 °C) which did not remelt on warming to room temperature. Spectral properties follow: IR (thin film) 3450 (broad), 3050, 2925, 2850, 1580, 1470, 1430, 1380, 1350, 1260, 1230, 1195, 1150, 1120, 1070, 1040, 1025, 1010, 960, 890, 860, 845, 790, 750, 740, 690 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 7.62–7.17 (m, 5 H, ArH), 3.60–3.12 (m, 1 H, CHO) 3.14 (s, 1 H, OH, disappears with added D_2O), 3.05–2.45 (m, 1 H, CHS), 2.42–0.90 (m, 8 H, CH_2).

Anal. Calcd for $C_{12}H_{16}OS$: C, 69.19; H, 7.74. Found: C, 69.26; H, 7.82.

***cis*-2-(Phenylthio)cyclohexanol).** A very low yield of *cis*-2-(phenylthio)cyclohexanol was obtained from the free-radical addition of thiophenol to 1-cyclohexenyl acetate.[25] The addition was attempted by irradiating a 5:1 mole ratio solution of thiophenol and 1-cyclohexenyl acetate with a Sylvania sun lamp. Catalysis was also accomplished by benzoyl peroxide. Reaction times up to 200 h and temperatures up to 150 °C were employed. Neither method gave satisfactory yields and the product was contaminated by diphenyl disulfide.

The reaction mixture was taken up in ether, washed with excess 3 N NaOH, then with water, dried ($MgSO_4$), and concentrated. Distillation of the residue yielded three fractions boiling between 45 and 85 °C (2 mm). From the pot residue a small amount of the acetate was separated by preparative GLC (8-ft 25% SE-30 on 60/80 mesh Chromosorb P, 200 °C): 60-MHz ^1H NMR ($CDCl_3$) δ 7.62–7.11 (m, 18 H, ArH), 5.23–4.94 (m, 0.7 H, CHO), 3.60–3.26 (m, 1 H, CHS), 2.50–1.10

(m, 8 H, CH_2), 1.90 (s, 2.9 H, $OCOCH_3$). Even with preparative GLC the diphenyl disulfide was not completely eliminated.

GLC analysis on the 5-ft 5% Carbowax 20M column at 185 °C showed one peak with a retention time of 28.2 min, which was slightly longer than the retention time of the trans isomer.

Anal. Calcd for $C_{12}H_{16}OS$: C, 69.19; H, 7.74. Found: C, 60.33; H, 7.81.

Trimethylsilyl Ethers. To a solution of 2.5 mol of the appropriate alcohol in 10 ml of dry benzene containing 1 ml of dry pyridine was added by means of a hypodermic syringe 1.0 ml of trimethylchlorosilane (TMCS) (Pierce Chemical Co.). A white precipitate of pyridine hydrochloride formed immediately. After standing with occasional shaking for 5–10 min, the solution was centrifuged. The supernatant liquid was analyzed by gas–liquid partition chromatography on a 5-ft column of 5% Carbowax 20M on Chromosorb W 60/80 mesh. The sample was introduced directly onto the column.

GLC analysis of an authentic mixture of the trimethylsilyl ethers of *cis*- and *trans*-2-(phenylthio)cyclohexanol showed two peaks with the same retention time as the individual ethers. Under no conditions, however, was baseline separation achieved.

Cooxidation Reaction Reduction Products and Trimethylchlorosilane. GLC analysis of the trimethylsilyl ethers of the reduced (diimide) alcohols obtained from crude cooxidation reaction mixture showed two peaks with retention times of 9.4 (1,2 isomers, peak 1) and 16.0 min (1,4 isomers, peak 2) at 190 °C. A chromatogram run at 160 °C still exhibited just two peaks at 22.6 (1,2 isomers) and at 42.5 min (1,4 isomers). At 150 °C two peaks were again observed. The first was fairly sharp and had a retention time of 30.1 min which corresponds quite closely with the retention time (under the same conditions) of the known trans 1,2 isomer (31.8 min). No evidence of a peak corresponding to the cis 1,2 isomer (retention time of 35.4 min) was observed. The second peak observed in the chromatogram run at 150 °C was a very broad, unsymmetrical peak which began coming off the column after 45 min. The peak slowly increased to its maximum height which occurred after 60 min and then dropped sharply to the baseline. No resolution of the 1,4 isomers is possible under these conditions. Peaks were identified by comparison of retention times with those of authentic samples of the Me_3Si ethers prepared from **7a**, and *cis*- and *trans*-4-(phenylthio)cyclohexanol.

***trans*- and *cis*-4-(Phenylthio)-2-cyclohexenyl *p*-Nitrobenzoate (1b and 2b).** A solution of 8.25 g (0.04 mol) of *trans*- and *cis*-4-(phenylthio)-2-cyclohexenol (**1a** and **2a**, fraction 3 from cooxidation chromatogram) in 125 ml of dry pyridine was cooled to 0 °C. Then 7.45 g (0.04 mol) of *p*-nitrobenzoyl chloride was added and the solution stirred for 2 h. The reaction mixture was poured into ether, washed with cold 3 N HCl, 10% $NaHCO_3$, and saturated NaCl solution, and dried ($MgSO_4$). The ether was removed using a rotary evaporator at aspirator pressure to give 13.3 g (93%) of a pale yellow solid, mp 49–85 °C. TLC on silica gel (HF) revealed two spots (R_f 0.53 and 0.41) when eluted with 20% ethane in hexane (v/v).

The mixture was chromatographed on a 4.5 × 100 cm column slurry packed with silica gel in hexane, eluting with 5% ether in hexane (v/v). Fractions (50 ml) were collected and analyzed by TLC (20% ether in hexane, v/v). In any given run three major fractions were obtained. The first, accounting for between 20 and 25% of the total collected weight, was a yellow solid, mp 75–78 °C, and exhibited a single spot on TLC (R_f 0.53). The middle fraction (55–65% of the total) contained both isomers. The third fraction (15–20% of the total), also a yellow solid, mp 100–102 °C, was the other isomer (R_f 0.41). In separate experiments the compound with R_f 0.41 was shown to be the cis isomer (**2b**), thus identifying the other (R_f 0.53) as **1b** (see oxidation of **1a** and **2a**).

Recrystallization of **2b** from 1:1 ethyl acetate–hexane (v/v) yielded a yellow solid: mp 103–104 °C; IR (KBr) 3050, 2950, 2850, 1720, 1600, 1520, 1480, 1440, 1340, 1310, 1270, 1120, 1100, 940, 885, 870, 820, 770, 740, and 715 cm^{-1}; ^1H NMR (100 MHz, $CDCl_3$) δ 1.5–2.64 (m, 4 H, ring methylenes), 3.8–4.12 (broad s, 1 H, CHS), 5.44–5.76 (broad s, 1 H, CHO), 5.84–6.44 (m, 2 H, vinyl), 7.0–7.92 and 7.96–8.76 (m, 9 H, aromatic).

Oxidation of **1b** (1.0 g) with 2 equiv of hydrogen peroxide in glacial acetic acid gave 0.91 g of crude product which upon recrystallization from ethyl acetate gave 0.51 g (47%) of **6b** as a white, granular solid: mp 169–170 °C dec; IR ($CHCl_3$) 3020 (s), 1720 (s), 1605 (m), 1505 (s), 1440 (m), 1350 (s), 1310 (s), 1270 (s), 1145 (s), 1135 (s), 1115 (s), 1100 (s), 1085 (s), 904 (m), 895 (m), 710 (m), 690 (m), 635 (m), 615 cm^{-1} (m); ^1H NMR (100 MHz, $CDCl_3$) δ 1.44–2.6 (m, 4 H, ring methylenes), 3.78–4.16 (broad singlet, 1 H, $CHSO_2$), 5.36–5.64 (broad singlet, 1 H, CHOCO), 6.0–6.20 (m, 2 H, vinyl), 7.28–8.40 (m, 9 H, aromatic).

Anal. Calcd for $C_{19}H_{17}NO_6S$: C, 58.90; H, 4.42; N, 3.61. Found: C, 59.12; H, 4.37; N, 3.60.

Reduction of *cis*-4-(Phenylthio)-2-cyclohexenyl *p*-Nitrobenzoate (2b). A solution of 0.271 g (7.6×10^{-4} mol) of the *p*-nitrobenzoate with the smaller R_f value (which this experiment shows to be **2b**) in 10 ml of benzene was mixed with a solution of 0.15 g (1.6×10^{-4} mol) of tris(triphenylphosphine)rhodium(I) chloride and allowed to stir under 1 atm of hydrogen at room temperature for 15 h. The solvent was removed by rotary evaporation and the residue chromatographed on Florisil eluting with 10% by volume ether in hexane. A single fraction was obtained whose ^1H NMR spectrum ($CDCl_3$) was identical with that of authentic *cis*-4-(phenylthio)cyclohexyl *p*-nitrobenzoate. The TLC R_f value likewise was identical with that of the cis isomer.

***cis*- and *trans*-4-(Phenylthio)-2-cyclohexenyl 3,5-Dinitrobenzoate (2c and 1c).** A solution of 3.9 g (1.89×10^{-2} mol) of a 1:1 mixture of *cis*- and *trans*-4-(phenylthio)-2-cyclohexen-1-ol in 25 ml of dry pyridine was cooled to 0 °C. Then 4.7 g (2.0×10^{-2} mol) of 3,5-dinitrobenzoyl chloride was added slowly and the solution stored in the refrigerator for 48 h. Pouring the reaction mixture into ice-cold 3 N HCl resulted in the precipitation of a yellow solid, which was filtered, washed with 3 N HCl, water, 10% sodium bicarbonate solution, and finally water, and thoroughly dried to yield 6.9 g (91%) of crude ester.

Recrystallization of the crude material from 20% ethyl acetate in hexane (v/v) yielded 2.7 g of yellow needles, mp 118.5–120 °C. The analysis of this solid showed it to be nearly pure and based on the results of the *p*-nitrobenzoates, it was assumed (later proved correct) to be the trans isomer (**1c**).

The residue, dissolved in a small amount of carbon tetrachloride, was chromatographed on a silica gel column with elution by 1% ethyl acetate in carbon tetrachloride (v/v). Following their separation, each isomer was recrystallized. Recrystallization of **1c** from 20% ethyl acetate in cyclohexane (v/v) gave a yellow solid: mp 120.5–121.5 °C; IR ($CHCl_3$) 3100, 2960, 2890, 1720, 1620, 1525, 1460, 1350, 1280, 1160, 1090, 1075, 1025, 995, 895, 880 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 9.30–8.90 (m, 3 H, ArH), 7.55–7.15 (m, 5 H, ArH), 6.20–5.95 (m, 2 H, vinyl), 5.70–5.45 (m, 1 H, CHO), 4.10–3.80 (m, 1 H, CHS), 2.40–1.70 (m, 4 H, CH_2CH_2).

Anal. Calcd for $C_{19}H_{16}N_2O_6S$: C, 56.99; H, 4.03; N, 7.00. Found: C, 57.40; H, 4.27; N, 7.03.

Recrystallization of the other isomer from 1:1 carbon tetrachloride–cyclohexane gave **2c** as a yellow solid: mp 114.5–115.5 °C; IR ($CHCl_3$) 3100, 2960, 1720, 1620, 1550, 1350, 1270, 1160, 1075, 1000, 985, 900, 880 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 9.30–9.00 (m, 3 H, ArH), 7.55–7.10 (m, 5 H, ArH), 6.15–5.90 (m, 2 H, vinyl), 5.70–5.45 (m, 1 H, CHO), 3.95–3.70 (m, 1 H, CHS), 2.30–1.90 (m, 4 H, CH_2CH_2).

Anal. Calcd for $C_{19}H_{16}N_2O_6S$: C, 56.99; H, 4.03; N, 7.00. Found: C, 56.58; H, 4.17; N, 6.88.

Reduction of *cis*-4-(Phenylthio)-2-cyclohexenyl 3,5-Dinitrobenzoate (2c). The homogeneous catalytic reduction of *cis*-4-(phenylthio)-2-cyclohexenyl 3,5-dinitrobenzoate was effected as described for **2b** from 0.46 g (1.15×10^{-3} mol) of the ester with the smaller R_f value (vide supra) and 0.17 g of catalyst. Following reaction for 72 h and the usual workup, a yellow, crystalline solid was isolated which had mp 128–132 °C after recrystallization from 20% ethyl acetate in cyclohexane (v/v). TLC analysis after one elution (20% ether in hexane) showed a single spot with an R_f value identical with that of the known cis.saturated ester. Multiple elutions showed two spots which could be ascribed to a mixture of the cis saturated ester and the cis unsaturated ester. No spot corresponding to **1c** was observed.

Oxidation of *trans*- and *cis*-4-(Phenylthio)-2-cyclohexenol (1a and 2a). A solution of 1.064 g (5.16×10^{-3} of a 1:1 mixture of **1a** and **2a** (fraction 3 from the cooxidation chromatogram) in 5 ml of dioxane was combined with a solution of 1.35 g (5.97×10^{-3} mol) of 2,3-dichloro-5,6-dicyano-1,4-benzoquinone in 20 ml of dioxane in a 50-ml Erlenmeyer flask and stoppered. The reaction mixture was allowed to stand with occasional swirling for 48 h at room temperature. A solid formed which was filtered and the filtrate concentrated by rotary evaporation. Column chromatography of the residue on silica gel with elution by ether yielded 1.05 g (84%) of a colorless liquid: IR (thin film) 3050, 2950, 1860, 1690, 1590, 1490, 1440, 1380, 1250, 1210, 1120, 1090, 1070, 1025, 830, 750, and 695 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 7.15–6.75 (m, 5 H, ArH), 6.65–6.35 (q, 1 H, vinyl), 5.75–5.45 (q, 1 H, vinyl), 3.90–3.55 (m, 1 H, CHS), 2.80–1.80 (m, 4 H, CH_2).

Anal. Calcd for $C_{12}H_{12}OS$: C, 70.55; H, 5.92. Found: C, 70.64; H, 5.82.

The spectral data combined with the single TLC spot and a single GLC peak confirm that the product is the expected 4-(phenylthio)-cyclohex-2-enone. This experiment shows that fraction 3 contains two alcohols which are epimers. Since one of the two *p*-nitrobenzoates

derived from this fraction was shown to be the cis 1,4 isomer **2b** (see above), the identity of the other benzoate as **1b** is established.

***trans*-6-(Phenylthio)-2-cyclohexenyl *p*-Nitrobenzoate (3b).** The reaction of 2.74 g (1.83×10^{-2} mol) of *trans*-6-phenylthio-2-cyclohexenol with 3.80 g (1.9×10^{-2} mol) of *p*-nitrobenzoyl chloride was effected as described above. The product was recrystallized from absolute ethanol to yield 4.6 g (71%) of pale yellow needles: mp 95.5–97 °C; IR (KBr) 3100, 3075, 3030, 2960, 2910, 2840, 1710, 1600, 1590, 1510, 1475, 1440, 1310, 1250, 1165, 1095, 1020, 1010, 910, 870, 860, 780, 735, and 700 cm^{-1}; ^1H NMR (100 MHz, $CDCl_3$) δ 1.84 (m, 1 H), 2.28 (m, 3 H), 3.60 (m, 1 H, CHS), 5.6–6.24 (m, 3 H, CHO and vinyl), 7.24–7.64 (m, 5 H, ArH), 8.2 (A_2B_2, 4 H, NO_2ArH).

Anal. Calcd for $C_{19}H_{17}NO_4S$: C, 64.21; H, 4.82; N, 3.94. Found: C, 64.37; H, 4.75; N, 3.93.

***trans*-2-(Phenylthio)cyclohexyl *p*-Nitrobenzoate (7b).** *trans*-2-(Phenylthio)cyclohexyl *p*-nitrobenzoate was prepared in the usual way from 6.0 g (0.028 mol) of *trans*-2-(phenylthio)cyclohexanol and 6.0 g (0.032 mol) of *p*-nitrobenzoyl chloride. Recrystallization of the crude product yielded 5.6 g (56%) of white needles: mp 110.5–111.5 °C; ^1H NMR (100 MHz, $CDCl_3$) δ 1.3–2.0 (m, 6 H, CH_2), 2.0–2.44 (m, 2 H, CH_2), 3.40 (m, 1 H, CHS, J = 9.2, 9.2, 4.1 Hz), 5.14 (m, 1 H, CHO, J = 9.2, 9.2, 4.1 Hz), 7.2–7.6 (m, 5 H, ArH), 8.16 (A_2B_2, 4 H, NO_2ArH); IR (KBr) 3065, 2925, 2850, 1715, 1600, 1515, 1465, 1435, 1340, 1315, 1265, 1125, 1095, 1025, 1010, 945, 935, 900, 865, 845, 825, 775, 750, 740, 710, 685 cm^{-1}.

Anal. Calcd for $C_{19}H_{19}NO_4S$: C, 63.85; H, 5.36; N, 3.92. Found: C, 63.84; H, 5.26; N, 3.95.

***cis*-4-(Phenylthio)cyclohexyl *p*-Nitrobenzoate.** In the usual manner, 2.0 g (9.6×10^{-3} mol) of *cis*-4-(phenylthio) cyclohexanol was reacted with 1.95 g (1.05×10^{-2} mol of *p*-nitrobenzoyl chloride to yield 2.1 g (61.5%) of white solid: mp 84.5–85 °C from absolute ethanol; IR (KBr) 3100, 3075, 2950, 1710, 1600, 1590, 1520, 1480, 1440, 1350, 1320, 1270, 1115, 1100, 1080, 930, 900, 870, 840, 805, 780, 745, and 715 cm^{-1}.

Anal. Calcd for $C_{19}H_{19}NO_4S$: C, 63.85; H, 5.36; N, 3.92. Found: C, 63.84; H, 5.46; N, 3.92.

***trans*-4-Phenylsulfonyl-2-cyclohexenyl 3,5-Dinitrobenzoate (6c).** Reaction of 2 equiv of H_2O_2 in glacial acetic acid with *trans*-4-(phenylthio)-2-cyclohexenyl 3,5-dinitrobenzoate (**1c**) prepared in the same manner as described for **1b** gave after recrystallization from acetone/water (9.5/0.5), 0.37 g (69%) of **6c** as pale yellow needles: mp 183–184 °C dec; IR (thin film) 3100 (m), 1330 (s), 1630 (m), 1550 (s), 1450 (m), 1345 (s), 1305 (s), 1275 (s), 1165 (s), 1145 (s), 1070 (m), 1000 (m), 885 (m), 725 (s), 690 cm^{-1} (s); ^1H NMR (100 MHz, $CDCl_3$) δ 1.6–2.6 (m, 4 H, ring methylenes), 3.95 (broad singlet, 1 H, $CHSO_2$), 5.52 (broad singlet, 1 H, CHOCO), 6.1–6.48 (m, 2 H, vinyl), 7.48–8.18 (m, 5 H, aromatic), 8.98–9.42 (m, 3 H, aromatic).

Anal. Calcd for $C_{19}H_{16}N_2O_8S$: C, 52.78; H, 3.73; N, 6.48. Found: C, 52.83; H, 3.52; N, 6.49.

Kinetic Procedures. Reaction rates were followed by titrating the production of *p*-nitrobenzoic acid or 3,5-dinitrobenzoic acid with NaOH (0.01 N) to the blue end point of bromothymol blue–bromocresol purple mixed indicator. Titration of standard solutions of either 3,5-dinitrobenzoic acid or *p*-nitrobenzoic acid in 2,2,2-trifluoroethanol (TFE) gave experimental titers that were within 4% of calculated titers. TFE was purified according to Dafforn and Streitweiser[26] and stored over 4A molecular sieves.

Solutions (0.01–0.15 M) were prepared by dissolving the weighed substrate and diluting with TFE in a 25-ml volumetric flask. Aliquots (2.5 ml) were transferred to ampules, sealed, and placed in a constant temperature bath. All temperatures from 50 to 100 °C are accurate to within ±0.05 °C while temperatures reported 110–120 °C are within ±0.2 °C. At appropriate time intervals, ampules were withdrawn and quenched in dry ice/acetone. After returning to room temperature, a 2-ml aliquot was pipetted into a 25-ml Erlenmeyer flask containing ca. 2 ml of H_2O and ca. 100 mg of indicator, and titrated with NaOH (0.01 N) to a light blue end point, the final volume in all cases being adjusted to 100 ml by addition of H_2O. All titrations were performed using a Koch self-filling microburet which could be read to 0.01 ml.

Excellent first-order rate plots were obtained to about 2–3 half-lives. Rate constants were computed from $\log (V_\infty - V_t) = -kt/2.03$ plots by the method of least squares. Unless otherwise noted, experimental infinity titers were used in all computations.

Product Studies. A. *trans*-6-(Phenylthio)-2-cyclohexenyl *p*-Nitrobenzoate (3b) in Buffered 2,2,2-Trifluorethanol. A solution (200 ml) of 1.401 g of **3b** (0.02 M) and 0.848 g of 2,6-lutidine (0.04 M) in TFE was sealed with a 300-ml round-bottom flask and heated at 65 °C for 10 half-lives. The solvent (TFE) was removed through a 10-cm Vigreux column until ca. 5 ml of liquid remained. The residue was taken up in ether (75 ml), washed twice with H_2O (15 ml), twice with 5% HCl (15 ml), and saturated $NaHCO_3$ (30 ml), and dried over K_2CO_3. Ether was removed through a 10-cm Vigreux column to give 2.535 g (ca. 60% TFE by ^1H NMR) of a pale amber-green liquid.

Table III. Chemical Shift Data and Splitting Patterns

Registry no.	Compd	Multiplicity[a]	δ_{CHS}[b]
60789-34-6	**3a**	Rough h	3.23
60789-35-7 (**1a**)	(**1a** + **2a**)	Broad s	3.78
60789-36-8 (**2a**)			
	3b	h	3.60
	1b	Broad s	3.96
	2b	Broad s	3.90
60789-37-9	**3d**	h	3.40
60789-38-0 (**1d**)	(**1d** + **2d**)	Broad s	3.82[c]
60789-39-1 (**2d**)			

[a] s = singlet, h = heptet. [b] Chemical shifts are in parts per million downfield from Me_4Si and the center of the signal is reported. [c] Estimated center.

The crude material was examined for the presence of elimination products (diene). The ^1H NMR of the crude material manifested the presence of an olefinic multiplet centered at ca. δ 5.9. The ratio of olefinic H to aromatic H to ring CH_2 was 2:5:4, as would be expected for the phenylthio substituted 2-cyclohexenyl trifluoroethyl ethers. No olefinic signals which could be ascribed to diene were present.

TLC analysis of the crude mixture on silica gel (5% ether/pentane, UV indicator) manifested the presence of three major components, R_f 0.49, 0.39, 0.16. Dry column chromatography (silica gel, 5% ether/pentane) and collecting the fractions by elution in the standard manner gave the separated components.

Fraction 1 (shown below to be a 10:10:80 mixture of **1d, 2d,** and **3d**) consisted of 0.758 g (68% of theory) of a colorless liquid exhibiting two spots on TLC (R_f 0.49, 0.39); ^1H NMR (100 MHz, $CDCl_3$) δ 1.46–2.54 (m, 4 H, ring methylenes), 3.24–3.56 and 3.60–4.38 (heptet, overlapping quartets, J_{HF} = 8.7 Hz, and multiplets, methine and OCH_2CF_3, total of 4 H), 5.54–6.2 (m, 2 H, vinyl), 6.88–8.08 (m, 5 H, aromatic).

Anal. Calcd for $C_{14}H_{15}F_3OS$: C, 58.33; H, 5.25. Found: C, 58.50; H, 5.39.

Fraction 1 consisted of a mixture of 6- and 4-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ethers (**1d, 2d,** and **3d**). Double resonance experiments were performed on fraction 1 in order to properly assign the spectrum. They rest on the fact that in **1d** and **2d** both the CHS and CHO protons are adjacent to vinyl protons but not to each other while in **3d** only the CHO and not the CHS proton is adjacent to a vinyl proton. These experiments are described below. Irradiation of the vinyl multiplet at 570, 580, or 587 Hz (note Hz × 0.01 = δ) had no effect on the heptet at δ 3.24–3.56 and conversely irradiation of the heptet at 338 Hz also had no affect on the multiplicity of the vinyl pattern. Irradiation of the ring methylenes at 204 Hz altered the multiplicity of the vinyl pattern and collapsed the heptet to a rough doublet, J = 6.0 Hz. The decoupling data were consistent with assigning the heptet at δ 3.24–3.56 to CHS of 6-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ether. Decoupling experiments performed with *trans*-6-(phenylthio)-2-cyclohexenol manifested the same behavior of CHS. Chemical shift data for CHS of **1a, 2a,** and **1b** relative to CHS of **3a** and **3b,** respectively, supported the assignment. Thus the chemical shifts of the CHS protons in **1** (**a, b,** or **d**) and **2** (**a, b,** or **d**) are consistently further downfield than those of **3** (**a, b,** or **d**); see Table III.

Analysis of the coupling constants ($-OCH^a-CH^bSPh-CH^cH^d-$) for **3d** gave J_{ab} = 6.0, J_{bc} = 8.0, and J_{bd} = 2.8 Hz. The analogous set of coupling constants for **3b** is 7.0, 9.1, and 3.0 Hz, which supports the trans-diequatorial conformation for **3d.** Furthermore, these values are in agreement for those reported for shikimic acid.[27]

Thus the CHS heptet at δ 3.40 was assigned solely to *trans*-6-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ether (**3d**). Expansion and careful integration of the signals at δ 3.40–4.38 gave an 80/20 ratio of **3d** to (**1d** + **2d**).

Fraction 2 gave 0.028 g (2.5% of theory) of a liquid exhibiting one spot on TLC (silica gel, 5% ether/pentane UV indicator): R_f 0.39; ^1H NMR (100 MHz) δ 1.4–2.42 (m, 4 H, ring methylenes), 3.72–4.30 (multiplet and two quartets, J_{HF} = 9.0 Hz, 4 H, CHO, CHS, and OCH_2CF_3), 5.84–620 (m, 2 H, vinyl), 6.90–8.04 (m, 5 H, aromatic). Irradiation of 408 Hz (ca. center of CHO envelope) and 382 Hz (ca. center of CHS envelope) changed the multiplicity of the vinyl pattern

at δ 5.84–6.20, consistent with the allylic nature of both methine protons. The height ratio of the quartet signals (OCH_2CF_3) at δ 3.90 and 3.88 was 51/49. The ^1H NMR data were consistent with the presence of *cis*- and *trans*-4-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ethers (**2d** and **1d**) in ca. equal amounts (51:49).

Fraction 3 gave 0.100 g (7% of theory) of material that slowly solidified. It was identified as *trans*-4-(phenylthio)-2-cyclohexenyl *p*-nitrobenzoate (**1b**). The ^1H NMR was identical with that of authentic **1b** as were TLC data. Recrystallization from ethyl acetate/cyclohexane gave pale yellow needles, mp 75.5–77 °C (no depression upon mixing).

Fraction 4 gave 0.008 g of a residue that remained unidentified.

B. *trans*-4-(Phenylthio)-2-cyclohexenyl *p*-Nitrobenzoate (1b) in Buffered 2,2,2-Trifluoroethanol. A solution of 1.164 g of **1b** (0.022 M) and 0.703 g of 2,6-lutidine (0.044 M) in TFE was solvolyzed at 97 °C for 10 half-lives. The workup is the same as that described for A. No ^1H NMR evidence for diene formation was found.

Fraction 1 gave 0.764 g (81% of theory) of a liquid exhibiting two spots on TLC (R_f 0.49, 0.39). ^1H NMR analysis showed fraction 1 to consist of 71% of *trans*-6-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ether (**3d**) and 20% of *cis*- and *trans*-4-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ethers (**2d** and **1d** in a 1:1 ratio).

Fraction 2 gave 0.028 g (3% of theory) of a liquid exhibiting one spot on TLC (R_f 0.39). The ^1H NMR manifested the presence of *cis*- and *trans*-4-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ether (**2d** and **1d**) in a 50/50 ratio.

Fraction 3 gave 0.019 g of a residue that remained uncharacterized.

C. *cis*-4-(Phenylthio)-2-cyclohexenyl *p*-Nitrobenzoate (2b) in Buffered 2,2,2-Trifluoroethanol. A solution of 0.7185 g of **2b** (0.021 M) and 0.469 g of 2,6-lutidine (0.043 M) was solvolyzed at 110 °C for 8 half-lives. The workup is the same as that described for A. No ^1H NMR evidence for diene formation was found.

Fraction 1 gave 0.387 g (66% of theory) of a liquid which by TLC and ^1H NMR analysis was consistent with a mixture of 75% of *trans*-6-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ether (**3d**) and 25% of *cis*- and *trans*-4-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ethers (**2d** and **1d** in a 43/57 ratio).

Fraction 2 gave 0.017 g (3% of theory) of a liquid which by TLC and ^1H NMR analysis was consistent with a 43/57 mixture of *cis*- and *trans*-4-(phenylthio)-2-cyclohexenyl 2,2,2-trifluoroethyl ethers (**2d** and **1d**).

Product Stability. A solution of 0.204 g (0.02 M) of a mixture of 71% of **3d** and 29% of (**1d** and **2d**), 0.116 g (0.02 M) of *p*-nitrobenzoic acid, and 0.152 g (0.04 M) of 2,6-lutidine in TFE was sealed and heated at 110 ± 0.2 °C for 49.5 h. The solvent was removed under reduced pressure until ca. 5 ml of liquid remained. The residue was taken up into ether (40 ml), washed with H_2O (15 ml), 5% HCl (15 ml), and saturated $NaHCO_3$ (15 ml), and dried (K_2CO_3). Removal of ether under reduced pressure resulted in quantitative recovery of the isomeric ethers. The percentage remained constant at 71% of **3d** and 29% of (**1d** + **2d**).

In order to discount the possibility that the above product distribution of 71% of **3d** and 29% of (**1d** + **2d**) represented an equilibrium mixture of the diastereometric ethers, the following experiment was performed. A solution of 0.40 g (0.02 M) of a mixture of 80% of **3d** and 20% of 69 (**1d** + **2d**) (obtained at 65 °C, 0.124 g (0.021 M) of *p*-nitrobenzoic acid, and 0.168 g (0.042 M) of 2,6-lutidine in TFE was sealed and heated at 110 ± 0.2 °C for 49 h. After the usual workup, 0.196 g (93%) of the mixture consisting of 83% of **3d** and 17% of (**1d** + **2d**) was recovered.

***cis*-4-(Phenylsulfonyl)-2-cyclohexenyl *p*-Nitrobenzoate (8b).** Two equivalents of H_2O_2 was added to a cooled and stirred slush containing glacial acetic acid (2 ml) and *cis*-4-(phenylthio)-2-cyclohexenyl *p*-nitrobenzoate (0.362 g). More acetic acid (3 ml) was added after the mixture was allowed to come to room temperature, and the reaction was continued for another 4.5 h at 25 °C. The solution was placed on a steam bath for 1 h and poured into ice-cold H_2O (10 ml). The crude sulfone (0.317 g) was recrystallized from ethyl acetate/hexane (1:4) to give 0.18 g (46%) of **8b** as pale yellow flakes: mp 103.5–105.5 °C; IR (KBr) 1715 (s), 1515 (s), 1438 (m), 1342 (s), 1330 (s), 1298 (s), 1265 (s), 1226 (m), 1130 (s), 1115 (s), 1100 (s), 1082 (s), 989 (s), 908 (m), 870 (m), 852 (m), 745 (s), 717 (s), 690 (s), 585 (s), 528 cm^{-1} (s); ^1H NMR δ 1.56–2.2 (m, 4 H, CH_2), 3.66–3.96 (rough triplet, 1 H, J = 6 Hz, $CHSO_2$), 5.45 (broad singlet, 1 H, CHOCO), 6.0–6.34 (m, 2 H, vinyl), 7.1–8.68 (overlapping multiplets, 9 H, aromatic).

Anal. Calcd for $C_{19}H_{17}NO_6S$: C, 58.91; H, 4.42; N, 3.61. Found C, 58.92; H, 4.54; N, 3.62.

Acknowledgments. The authors gratefully acknowledge financial support of this work by the National Science Foundation and wish to thank Mr. David Baillargeon for preparation and solvolysis of **8b**.

Registry No. —**1c**, 60789-40-4; **2c**, 60789-41-5; **6c**, 60789-42-6; **7a**, 35550-80-2; 2,2,2-trifluoroethanol, 75-89-8; 4-(phenylthio)cyclohex-2-enone, 60789-43-7; 3,5-dinitrobenzoyl chlorid, 99-33-2; 1,3-cyclohexadiene, 592-57-4; thiophenol, 108-98-5; *cis*-4-(phenylthio)-cyclohexanol, 34209-61-5; cyclohexene oxide, 930-68-7; *cis*-2-(phenylthio)cyclohexanol, 60789-44-8; 1-cyclohexenyl acetate, 1424-22-2; *p*-nitrobenzoyl chloride, 122-04-3; *cis*-4-(phenylthio)cyclohexyl *p*-nitrobenzoate, 60789-45-9.

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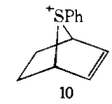

10

believe that this possibility is highly unlikely because of the overall similarity of the product ratios from **1b**, **2b**, and **3b**. Furthermore, the observed formation of cis 4 ether **2d** would not be expected from **10**.
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